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Faecal near infrared reflectance spectroscopy (F.NIRS) measurements of non-grass proportions in the diet of cattle grazing tropical rangelands

D. B. Coates[A,C] *and R. M. Dixon*[B]

[A]Davies Laboratory, CSIRO, PMB, PO, Aitkenvale, Townsville, Qld 4814, Australia.
[B]Department of Primary Industries & Fisheries, PO Box 6014, Rockhampton, Qld 4702, Australia.
[C]Corresponding author. Email: david.coates@csiro.au

Abstract. Frequent faecal near infrared reflectance spectroscopy (F.NIRS) analyses of faeces from cattle grazing a range of tropical pastures were used to measure the non-grass component, and other aspects, of their diets. Seasonal profiles of non-grass and crude protein in the diet are presented for nine sites from the speargrass, *Aristida–Bothriochloa*, and Mitchell grass dominated pasture regions, and for three shrubland sites where browse was plentiful. In grass-dominated native pastures of the speargrass and *Aristida–Bothriochloa* pasture regions of Queensland where little browse was available, non-grass was usually only 5–15% of the diet. Diet non-grass was even lower for a buffel grass pasture. In uncleared eucalypt woodland in the speargrass region, browse may have contributed up to 20% of the diet in the late dry season when grasses were senesced. In regions with abundant browse (e.g. mulga lands and desert upland systems) cattle preferentially selected actively growing grasses and forbs when they were available. With diminishing availability or declining quality of the forbs and grass due to grazing selection and dry conditions, browse increasingly contributed to intake. In Mitchell grass dominated pastures forbs often comprised more than 50% of the diet, and there appeared to be strong selection for forbs during the dry season. Where browse was available in association with Mitchell grass dominated pastures, it appeared to contribute to intake only in the late dry season. Dry season sampling in monsoonal tallgrass and Mitchell grass dominated pastures indicated dietary crude protein to be linearly correlated with diet non-grass, demonstrating the importance of non-grass in the prevention or alleviation of dry season protein deficiency in cattle. Changes in diet selected by cattle in relation to season and rainfall were generally in accord with the previous limited information, largely with sheep, in comparable vegetation systems. The results demonstrate the value of F.NIRS technology to assist understanding of diet selection by grazing cattle in northern Australia.

Additional keywords: *Aristida–Bothriochloa*, browse, diet selection, Mitchell grass, speargrass.

Introduction

Since cattle grazing the rangelands of northern Australia depend primarily on the vegetation on offer for their nutritional requirements, an understanding of the forage selected is obviously important for sound nutritional management. However, diet selection by cattle grazing the rangelands of northern Australia is poorly understood, largely because of the variety and complexity of the vegetation and herbivore selection, and the inadequacy of experimental methods. Nevertheless, it is clear that cattle grazing native vegetation systems do select a wide variety of plant species and morphological components, and that this selection has important implications for managing cattle for production and rangelands for sustainability (Squires 1980; Holechek 1984; Wilson and Harrington 1984; Volesky and Coleman 1996). Measurement of the botanical composition of diets selected by grazing cattle and sheep has until recently depended on techniques employing oesophageally-fistulated animals, histological examination of undigested plant material in faeces, disappearance of plant components from pasture over defined intervals, and observation of grazing animals. Each of these techniques may involve large inaccuracies and require substantial experimental resources (Holechek *et al*. 1982; Coates *et al*. 1987; Gordon 1995). Information is particularly lacking for cattle grazing the unimproved rangelands of northern Australia. Studies on diet selection by sheep (Wilson 1976; Lorimer 1978; Graetz and Wilson 1980; Harrington 1986; McMeniman *et al*. 1986; Orr *et al*. 1988) can provide additional information but extrapolation of diet selection from measurements with sheep to cattle may be misleading (Dudzinski and Arnold 1973; Wilson 1976; Squires 1980; Graetz and Wilson 1980).

Faecal NIRS has been developed to provide a practical and inexpensive tool to measure various dietary and faecal attributes (e.g. diet crude protein concentration, digestibility, neutral detergent fibre and acid detergent fibre, faecal N and faecal ash) in free ranging ruminants (Brooks *et al*. 1984; Lyons and Stuth 1992; Leite and Stuth 1995; Coates 2004). It has also been used to measure the proportions of specific plant species, or groups of plant species, in the diet (Walker *et al*. 1998, 2002; Decruyenaere *et al*. 2004; Landau *et al*. 2004). One difficulty with this approach is that major experimental resources would

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be required to develop calibration equations for even a few plant species in a few well defined grazing systems. To avoid this latter constraint in developing F.NIRS calibrations, Coates (2004), following Clark *et al*. (1995), utilised F.NIRS to measure faecal $\delta^{13}C$ together with the observation by Jones *et al*. (1979) that the $\delta^{13}C$ of faeces is proportional to the ratio of C_3 to C_4 plants in the diet. This approach was based on the observation that, in the tropics and subtropics, pasture grasses are predominantly C_4 species (Hattersley 1983), whereas most of the non-grass species are C_3, and the proportion of grass to non-grass in the diet of ruminants grazing these communities is linearly related to the $\delta^{13}C$ of faeces (Jones *et al*. 1979). The calibration equations developed by Coates (2004) enable faecal $\delta^{13}C$ to be measured by F.NIRS analysis and the proportion of non-grass in the diet can be calculated from predicted faecal $\delta^{13}C$ as reported by Jones (1981). Determining diet non-grass proportions (DNG) using F.NIRS can, therefore, be done concurrently with the prediction of other dietary and faecal attributes without additional cost, since all predictions are derived from the same faecal NIR spectra.

In this paper we present faecal profiles of DNG from a range of primarily native pasture systems in northern Australia to demonstrate the practical application of the technology in providing reliable information on the contribution of non-grass to dietary dry matter (DM) intake, and the effect of seasons, years and rainfall patterns on DNG. We also present data on the influence of DNG on the nutrient status of the diet. The results are discussed in terms of the perceived importance of non-grass to cattle production and F.NIRS as a research, an educational and a decision support tool.

Materials and methods

Faecal sampling, processing and analysis

Diet non-grass was measured from NIR spectra of dried, milled faecal samples using the calibration equation developed and described by Coates (2004). The equation measured faecal $\delta^{13}C$ and was derived from a calibration set of 1501 faecal samples sourced from cattle grazing pastures, where all grasses were C_4 species and all non-grass plants were C_3 species. Reference $\delta^{13}C$ values were determined by mass spectrometry. The calibration samples were derived from many locations across northern Australia and represented different pastures systems, seasons and years. Calibration equation statistics were as follows: standard error of calibration (SEC) = 0.76‰, standard error of cross validation (SECV) = 0.78‰, $R^2 = 0.94$. These equation statistics, together with the diversity encompassed by the calibration set, indicated a robust calibration equation capable of providing reliable predictions when applied to cattle faeces from most northern Australian pastures. The following formula was used to calculate DNG from predicted faecal $\delta^{13}C$:

$$\text{Non-grass (\%)} = (\text{faecal } \delta^{13}\text{C} - 13.5) \times 7.14 \qquad (1)$$

This assumed that the average faecal $\delta^{13}C$ values for C_4 grass and C_3 non-grass diets were [13.5]‰ and [27.5]‰, respectively (based on Jones 1981). Although the accuracy of determination of dietary C_3 and C_4 plant proportions from faecal $\delta^{13}C$ can be improved if allowance is made for digestibility differences between these dietary components (Jones 1981), such correction was not possible in the present studies.

Diet crude protein (CP) concentration, diet DM digestibility and ash concentration in faeces were also measured from the NIR spectra of faeces using calibration equations described by Coates (2004). Calibration statistics were $n = 1202$, SEC = 1.03%, SECV = 1.08%, $R^2 = 0.95$ for diet CP; $n = 1123$, SEC = 2.00%, SECV = 2.03%, $R^2 = 0.89$ for diet DM digestibility; and $n = 1168$, SEC = 2.00%, SECV = 2.06%, $R^2 = 0.90$ for faecal ash.

Faecal samples were collected either by sampling per rectum when the animals had been mustered, or by sampling from fresh dung in the paddock, usually near water points. Where possible, samples from at least 10 head or dung pats were collected, although herd size was lower in some experiments. Samples from a herd were thoroughly mixed before further processing. They were sometimes stored frozen, but were more often dried immediately. Drying was at 65°C in a forced draft oven followed by storage in the laboratory at ambient temperature.

Subsamples of dried faeces for NIRS analysis were ground through a 1 mm screen in Model 1093 Cyclotec Mill (Foss Tecator AB, Hoganas, Sweden). Prior to analysis samples were redried at 65°C, cooled to ambient temperature, packed into ring cups and, using a spinning cup module, scanned in the 400–2500 nm range using a scanning monochromators instrument (Model 6500, NIRSystems, Inc., Silver Spring, MD, USA). Samples were stored in desiccators before packing into the ring cups, and then before scanning, to prevent uptake of moisture. Spectral data were analysed using ISI software (Infrasoft International, Port Matilda, Penn.).

Experimental sites

Faecal NIRS profiles of DNG and diet CP are presented for 12 sites in Queensland, described in Table 1. These datasets were chosen on the basis of continuous, long duration and regular sampling to illustrate the selection of non-grass by cattle grazing a variety of pasture systems. The sites encompassed a range of environments, particularly with respect to the amount and distribution of rainfall, soil types, and vegetation communities. Nine were research sites where there was good control over the experimental cattle and where faecal sampling was carried out on a regular, predetermined schedule. The other three sites were paddocks located on commercial properties. Except where otherwise stated, each site was stocked with young *Bos indicus* or *B. indicus* × *B. taurus* cattle, or at one site, Longreach Pastoral College (LPC), *Bos taurus* cattle adapted to the region. Stocking rate on all 12 sites was moderate by regional industry standards, except one additional high stocking rate treatment at Glentulloch. However, because of low rainfall in some years at some sites, pasture on offer was sometimes reduced to low levels.

In addition to the sites described in Table 1, measurements from three commercial properties were chosen to illustrate the influence of DNG on dry season diet quality, and, in particular, on protein concentration. At these sites, herds from several paddocks were sampled at the same time so that the correlation between diet CP and DNG could be determined. The three properties were Newcastle Waters (17°22′S; 133°25′E), ~100 km south of Daly Waters, NT; Carlton Hill Station

Table 1. Description of the 12 experimental faecal profiling sites showing coordinates, mean annual rainfall (MAR), pasture type and soil type

Site	Description
Northern and southern speargrass regions	
Swans Lagoon Res. Stn. 20°4′S; 147°15′E, 870 mm MAR	Eucalypt woodland in the coastal speargrass region of N-E Qld. with native pasture of black speargrass [*Heteropogon contortus* (L.) Roem. & Schult], ribbon grass (*Chrysopogon fallax* S.T. Blake), naturalised Indian couch grass [*Bothriochloa pertusa* (L.) A. Camus], some annual grasses, legumes and forbs on a low fertility sodic duplex soil
Brian Pastures Res. Stn. 25°40′S; 151°45′E, 703 mm MAR	Eucalypt woodland with most trees killed in the southern speargrass region with native pasture of black speargrass, forest bluegrass [*Bothriochloa bladhii* (Retz.) S.T. Blake], some Indian couch and some native legumes and other forbs on soil of basaltic origin
Forest Home Stn. 19°56′S; 146°31′E, 660 mm MAR	Semi-cleared eucalypt woodland with pasture dominated by Indian couch plus some native legume [*Indigofera colutea* (Burm.f.) Merr.] and the woody weed *Carissa lanceolata* R. Br. (currant bush) on red chromosols derived from granodiorite
Aristida–Bothriochloa *region*	
Frankfield Stn. 22°16′S; 147°6′E, 544 mm MAR	Cleared brigalow country with pasture of buffel grass (*Cenchrus ciliaris* L.) on moderately fertile cracking clay soils and managed under a cell grazing system
Glentulloch Res. Site 25°45′S; 148°24′E, 607 mm MAR	Paddocks of low and high grazing pressure (25% and 75% utilisation), with trees killed, in a grazing trial near Injune (*Aristida–Bothriochloa* region); pasture of Queensland bluegrass [*Dichanthium sericeum* (R. Br.) A. Camus], pitted bluegrass (*Bothriochloa decipiens* var. *decipiens* C.E. Hubb.) and other native perennial grasses on texture contrast soils of surface loam over dense yellow clay
Mitchell grass pastures of western Queensland	
Rosebank Res. Stn. 23°32′S; 144°16′E, 434 mm MAR	Mitchell grass downs of central-western Queensland (Longreach) with pasture of Mitchell grasses [*Astrebla lappacea* (Lindl.) Domin and *A. pectinata* (Lindl.) Benth.], Flinders (*Iseilema* spp.), feather top (*Aristida latifolia* Domin) and bluegrasses with numerous leguminous and non-leguminous forbs on grey cracking self mulching clays
Longreach Past. College 23°25′S; 144°16′E	Similar to Rosebank
Toorak Res. Stn. 21°2′S; 141°48′E, 439 mm MAR	Mitchell grass downs of north-western Queensland (Julia Creek). Mitchell/Flinders grass pastures similar to those at Rosebank but rainfall at Toorak is highly summer dominant in contrast to more even distribution in central-western Queensland
Morungle Stn. 20°26′S; 142°55′E, 475 mm MAR	Equal parts of (a) Mitchell grass downs and (b) open woodland with white speargrass (*Aristida leptopoda* Benth.), forest Mitchell [*Bothriochloa ewartiana* (Domin) C.E. Hubb], buffel grass, shrubby stylo (*Stylosanthes scabr* cv. *Seca*) plus various browse species
Pastures with significant browse species	
Croxdale Res. Stn. 26°29′S; 146°9′E, 491 mm MAR	Low rainfall grass-browse pasture system of S-W Qld. near Charleville consisting of (a) Coolibah flats (*Eucalyptus coolabah* Blakely & Jacobs) of black/grey clays and loams with Queensland bluegrass, Mitchell grasses and kangaroo grass (*Themeda triandra* Forssk) and (b) red sands with mulga (*Acacia aneura* Benth.), turkey bush (*Eremophila deserti* (Cunn. ex Benth.) R.J. Chinnock) and wilga (*Geijera parviflora* Lindl.), kangaroo and wire grasses, and annual grasses mulga oats (*Monochather paradoxa*), mulga Mitchell [*Thyridolepis mitchelliana* (Nees) S.T. Blake]
Ryandale Stn. 28°1′S; 146°45′E, 394 mm MAR	Commercial paddock of ‘hard’ mulga country east of Cunnamulla with mulga the dominant browse species together with wiregrasses, annual grasses (mulga Mitchell and mulga oats) and forbs following rainfall events
Oakley Stn. 21°0′S; 145°3′E, ≈500 mm MAR	South of Torrens Creek on the northern edge of the Desert Uplands. Paddocks carried dense stands of quinine (*Petalostigma pubescens* Domin) with wattle, ironbark, currant bush, black speargrass and wiregrass growing on infertile sands overlying yellow clay

(15°30′S; 128°32′E), 30 km north-west of Kununurra, WA; and Woolthorpe (22°24′S; 145°14′E) ~70 km north of Aramac, Qld. Newcastle Waters and Carlton Hill Station are located within the monsoonal tropics and were stocked with *B. indicus* or *B. indicus* cross breeders. Newcastle Waters has a mixture of Mitchell grass country on black clay soils and timbered tropical tallgrass pastures on less fertile red soils, and Carlton Hill has timbered tropical tall grass pastures and marine plains. Woolthorpe is on the eastern edge of the Mitchell grass country of southern Queensland, and measurements were made with flocks of merino sheep.

Results

Northern and southern speargrass, Aristida–Bothriochloa *pasture regions, sown buffel grass pasture*

Faecal NIRS profiles of DNG (Figs 1, 2) show that, when stocking rate was moderate, non-grass proportions were low at all sites, generally in the range of 0–20%, although exceeding 30% on rare occasions and averaging between 9 and 12% except for the sown buffel grass pasture at Frankfield where the average was 4%.

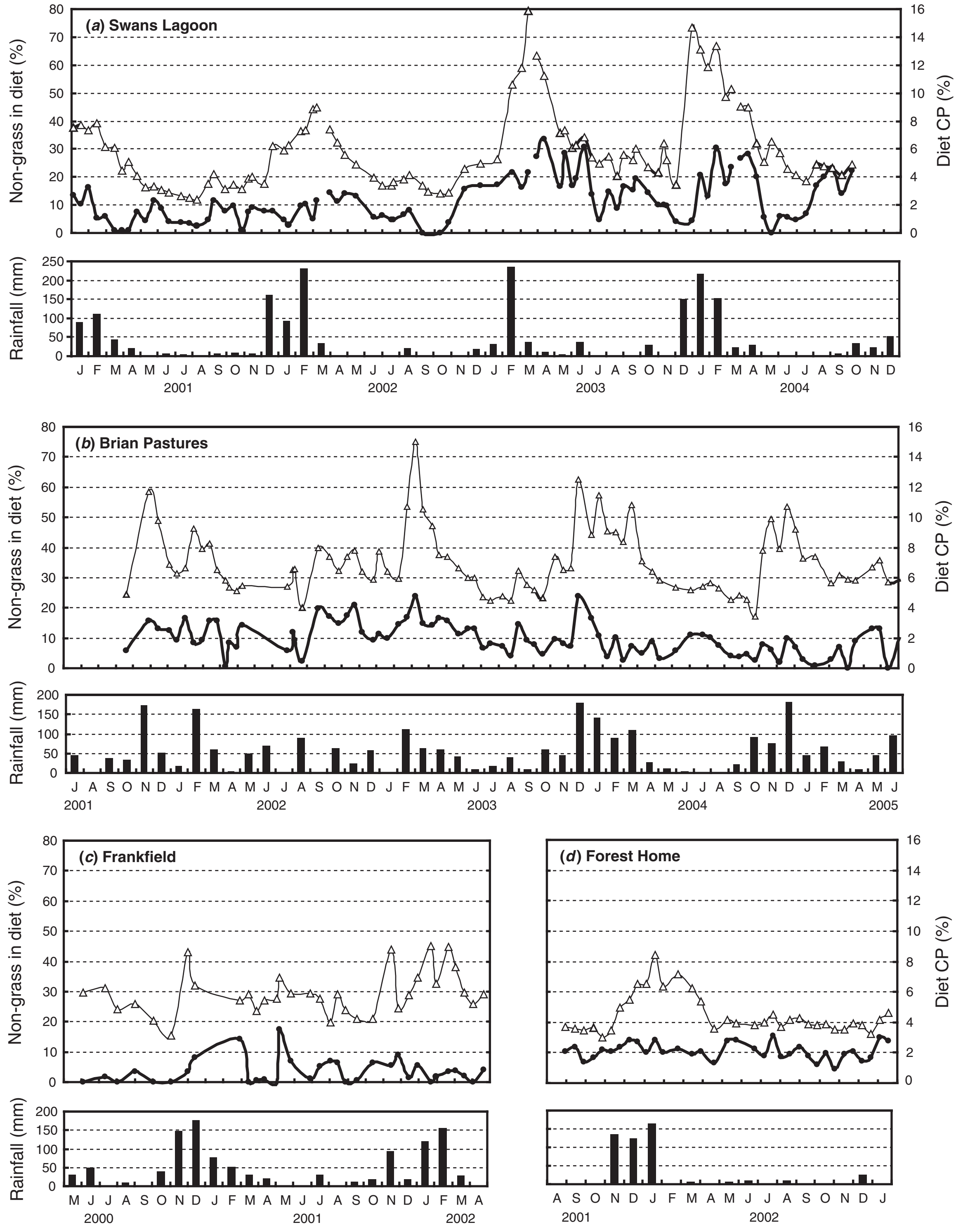

Fig. 1. Faecal NIRS predictions of diet non-grass proportions (●) and crude protein concentration (△) and monthly rainfall, over several years at (*a*) Swans Lagoon in the northern speargrass region, (*b*) Brian Pastures in the southern speargrass region, (*c*) Frankfield north of Clermont, and (*d*) Forest Home east of Charters Towers.

The results from Swans Lagoon (Fig. 1*a*) revealed that DNG tended to be highest during the wet season and lowest during the mid-dry season of each year (July–August in 2001, September–October 2002, July 2003, and May–July 2004) and then to rise again before effective opening rains to the wet season (September–October 2001, December–January 2002–03,

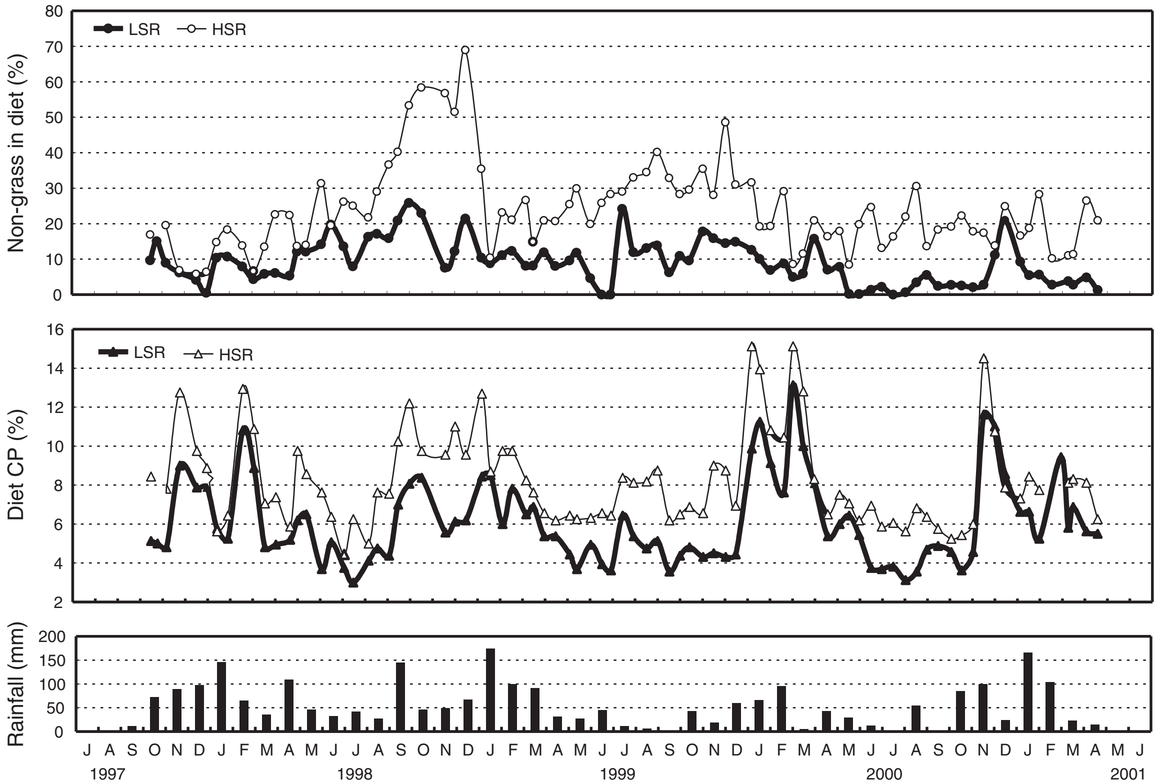

Fig. 2. Faecal NIRS predictions of diet non-grass proportions at low (●) and high (○) stocking rate and diet crude protein concentration at low (▲) and high (△) stocking rate at Glentulloch north-west of Injune for the period October 1997–April 2001, together with monthly rainfall recorded at the site.

September–October 2003 and August–September 2004). Predicted diet CP levels also rose with the increase in DNG in the late dry. We propose that the decline in DNG from the wet season into the dry season was due to diminishing availability of native legumes and other forbs as they were eaten, while the increase in DNG in the late dry season was probably due to cattle eating browse in this open eucalypt woodland at a time when protein concentration in the dry standing grass was very low. Between-year differences were apparent, with an appreciable increase in DNG during years 2003 and 2004 (means of 16.5 and 16.1%, respectively) compared with 2001 and 2002 (means of 6.7 and 7.7%, respectively). This was probably due to the cumulative adverse effect of well below average rainfall in 2001–02 and 2002–03 on the vigour and competitiveness of grass and an increase in the availability of forbs. There was a highly significant and positive correlation between diet CP and DNG ($P < 0.001$, $R^2 = 0.32$), but this was probably due, at least in part, to DNG being highest in the wet season when pasture quality overall was highest.

At Brian Pastures rainfall was more evenly distributed than at the northern sites. DNG averaged ~10% for the entire sampling period (range 0–24%), and we could not discern any consistent pattern between DNG and season or rainfall (Fig. 1*b*) whereas diet CP concentrations always declined during intervals of low or nil rainfall. Since no browse was available except for scattered ironbark and bloodwood tress, the non-grass in the diet was presumably due to ingestion of native legumes or other forbs, and it is likely that low DNG was the result of low availability of the non-grass pasture components. There was a positive correlation ($P < 0.001$, $R^2 = 0.25$) between diet CP and DNG.

At Frankfield (Fig. 1*c*) DNG was lower than at all the other sites, averaging only 4% and never exceeding 20%. Since the cattle grazed within a cell system the temporal fluctuations in predicted DNG were probably influenced mainly by availability as cattle moved from one paddock to another or one block of paddocks to another block. Diet CP was not correlated with DNG over the sampling period ($P = 0.42$).

At Forest Home (Fig. 1*d*) DNG averaged 11% and varied within only a narrow range of 5–15%. There was no discernable pattern between DNG and season or rainfall. In particular, the results indicated that DNG did not increase during the long dry season of 2002, despite the low diet CP concentrations and the availability of the native *Indigofera*, currant bush, and eucalypt trees and seedlings. Although there was a significant and positive correlation between diet CP and DNG ($P < 0.05$), the correlation was weak ($R^2 = 0.15$). Since grass was the dominant dietary component, diet CP was determined primarily by grass quality which in turn was dependent on rainfall.

The rainfall distribution at Glentulloch (Fig. 2), with registrations of 27 mm or more in every month for the period October 1997–June 1999, was, like that at Brian Pastures, in marked contrast to the highly seasonal distribution at the northern sites. We could not discern any consistent pattern between DNG and seasons or rainfall, nor was diet CP correlated with DNG at either high or low utilisation rate ($P = 0.51$ and 0.60 at the low and high utilisation rates, respectively). Diet non-grass and diet CP were higher in cattle grazing the high utilisation rate paddock compared with the low utilisation rate paddock with differences averaging 15 and 2.15% for DNG and diet CP, respectively. However, in the analysis of variance for the whole experiment which was a replicated factorial of three utilisation rates (25, 50 and 75%) by two timber treatments (trees alive and trees killed), the effect of utilisation rate on DNG was not significant ($P > 0.05$).

Mitchell grass dominated sites

At all Mitchell grass dominated sites (Fig. 3), DNG was appreciably higher than at the moderately stocked speargrass and *Aristida–Bothriochloa* sites, with mean values of 35% at Rosebank, 32% at LPC, 32% at Toorak and 21% at Morungle. Non-grass comprised a high proportion (30–70%) of the diet during the wet season. No data were available on the botanical composition of pasture during the wet season, but the results suggested that cattle did not select against non-grass, and may have selected for non-grass, during the wet season.

Rainfall at the Rosebank site during 1997–2000 was ~30% higher than the long-term mean of 434 mm, and the seasonal distribution was generally favourable for growth of forbs. This occurred especially during 1998 and 1999 when DNG often exceeded 50%. Mean diet CP was also high during most of that period, but diet CP was not correlated with DNG across samplings. In contrast to the Rosebank data, results from the other Longreach site, LPC, were associated with years of well below average rainfall and dry winters (Fig. 3*d)*. Nevertheless, mean DNG was comparable with that at Rosebank and was usually in the range 15–40% but declined to just above 10% in the late dry season of 2004. In 2002–03 diet CP was not correlated with DNG but there was a highly significant correlation for the 2004–05 period ($P < 0.001$, $R^2 = 0.79$).

When the trial began at Toorak, the pastures were very grass dominant and estimates of botanical composition of the pasture in the early dry in May of both 2001 and 2002 indicated the non-grass constituted <2% of pasture on offer. Nevertheless, the F.NIRS estimate of DNG in September 2001 was over 30%, although this declined rapidly with grazing. Also, throughout the 9-month dry season of 2002, DNG averaged nearly 17%. This clearly demonstrated a high level of selection for the non-grass component. Both the proportion and yield of non-grass in the pasture were appreciably higher in 2003 and 2004, such that in May of these years non-grass comprised 32 and 19% of total pasture on offer, respectively. Selection by cattle for non-grass resulted in high DNG levels that averaged 38%. Over the 4-year period diet CP was positively correlated with DNG ($P < 0.001$) but the coefficient of determination was low at only 0.24.

Above average rainfall was received at the Morungle site during the 2001–02 wet season. Diet non-grass increased briefly to ~30%, decreased to less than 20% during the wet period Dec-Jan, and then increased sharply in February to over 40% of the diet (Fig. 3*c*). This was followed by a steep decline during April to a value in June of <10%, after which it increased again to average 23% for the remaining 5 months of the dry season, August–December 2002. We propose that the decline in DNG during the early dry season was associated with depleted availability of forbs, while the subsequent increase was probably due to cattle utilising browse species. It is noteworthy that diet CP concentrations also fell sharply with the decline in DNG over the April–June interval and then rose by ~1% with the late dry season increase in DNG.

Pastures with substantial browse available

Conditions were dry when sampling commenced at Ryandale and the observation that the diet consisted entirely of non-grass was consistent with the advice from the property owner that the cattle were being fed on pushed mulga (Fig. 4*a*). Predictions of over 90% DNG continued through to June 2003, though some rain was received during the autumn and early winter. Following more substantial rain in July which clearly promoted some growth of grass there was a brief but substantial decrease in DNG to less than 80% before it increased again. After nearly 100 mm rain in January 2004, DNG decreased to ~30% of the diet. Information on the relative contributions of browse foliage and herbaceous forbs to DNG was obtained from concurrent F.NIRS measurements of faecal ash and the findings from an experiment where various proportions of mulga foliage and grass hay were fed to cattle in pens (M. Jeffery, personal communication). The pen trial results indicated that faecal ash concentration was negatively correlated with the proportion of mulga in the diet. The faecal ash profile for Ryandale (Fig. 4*a*) showed low faecal ash concentrations of 12–14% for December 2002–April 2003, then an increase in faecal ash to 16% in May–June 2003, followed by a further increase to at least 20% for the remainder of the trial period. These faecal ash concentrations therefore indicated that the non-grass in the diet was principally mulga until the end of March 2003, that a lesser amount of mulga and an increased proportion of forbs was selected after the autumn–early winter rain in May–June, and that the non-grass was principally herbaceous forbs from July 2003 through to the end of the trial period. In February 2004, following the rain in January, DNG decreased to only 30% indicating that the cattle were then consuming mainly grass rather than forbs. Diet CP predictions were consistent with forbs constituting the majority of the diet from July 2003 through to January 2004.

At Croxdale (Fig. 4*b*), cattle selected <15% non-grass during the 2001–02 wet season (November–March) and up to only ~20% non-grass through the dry season from May to October 2002. There was a sharp increase in DNG to almost 80% at the end of the dry season in January 2003, followed by a sharp decrease after the substantial rain in February 2003. It later increased to over 40% in early June. We speculate that the cattle selected some browse during the dry season, that there was some increase in selection of browse in November 2002 and a major increase in January 2003 owing to the lack of alternative forages. Grass growth from the rain in February 2003 led to a sharp decrease in DNG, but with the lack of follow-up rain the cattle again changed their diet to include more browse. Faecal ash concentrations, which were low in late January and in June, provided supportive evidence for this change in diet selection. Dietary CP was highest following substantial rainfall during the 2001–02 wet season, and following the rain in February 2003, when cattle were apparently selecting for actively growing grasses.

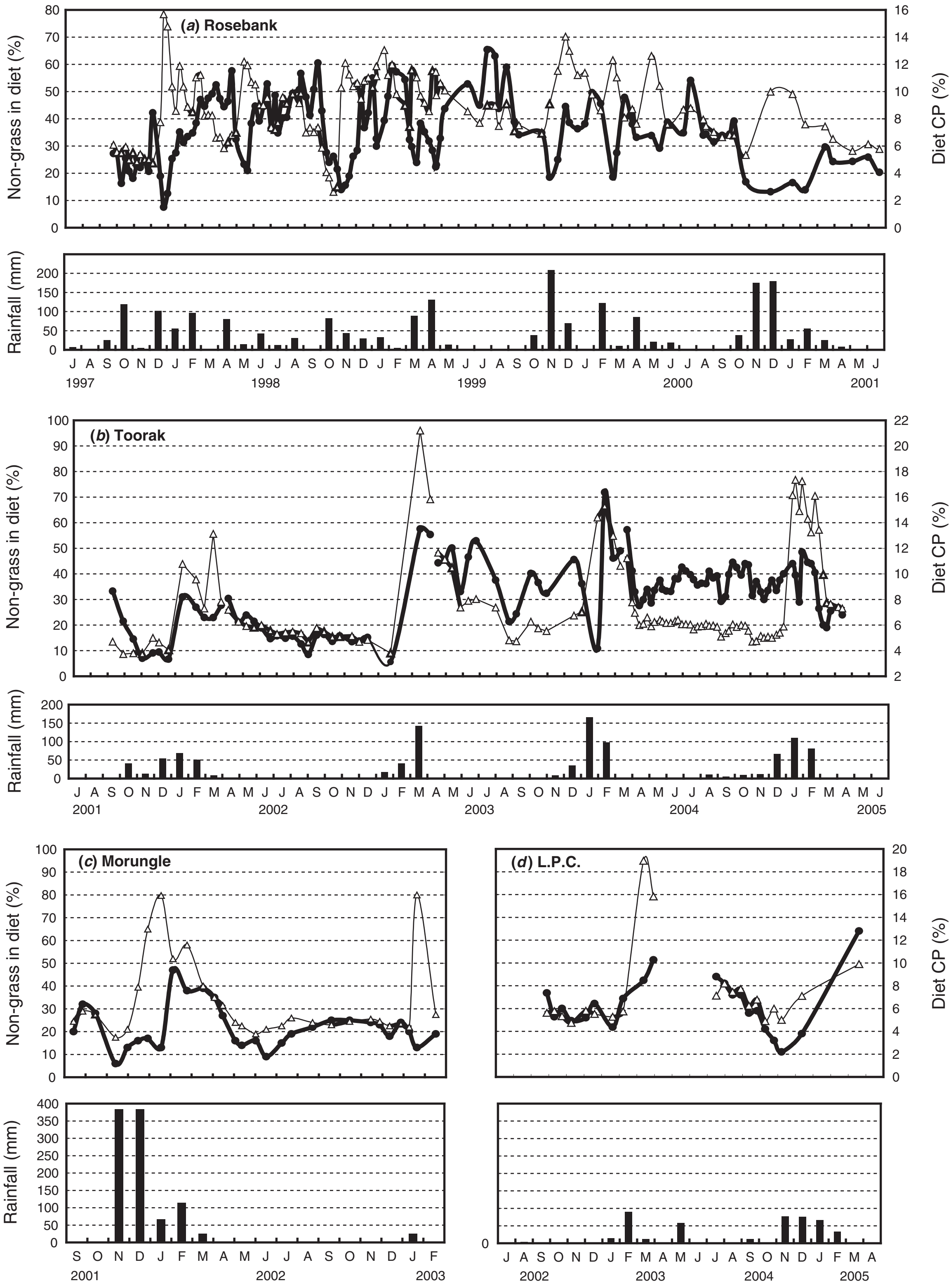

Fig. 3. Faecal NIRS predictions of diet non-grass proportions (●) and crude protein concentration (△) and monthly rainfall at (*a*) Rosebank near Longreach, (*b*) Toorak near Julia Creek, (*c*) Morungle near Richmond, and (*d*) Longreach Pastoral College.

Conditions were also dry at Oakley Station when sampling commenced in the middle of the dry season in July 2001 and DNG ranged between 50 and 70% through until December 2001 (Fig. 4*c*). A sharp decrease during January–March 2002 to <10% DNG in March was associated with substantial rain in January–February. Through the dry season the non-grass was

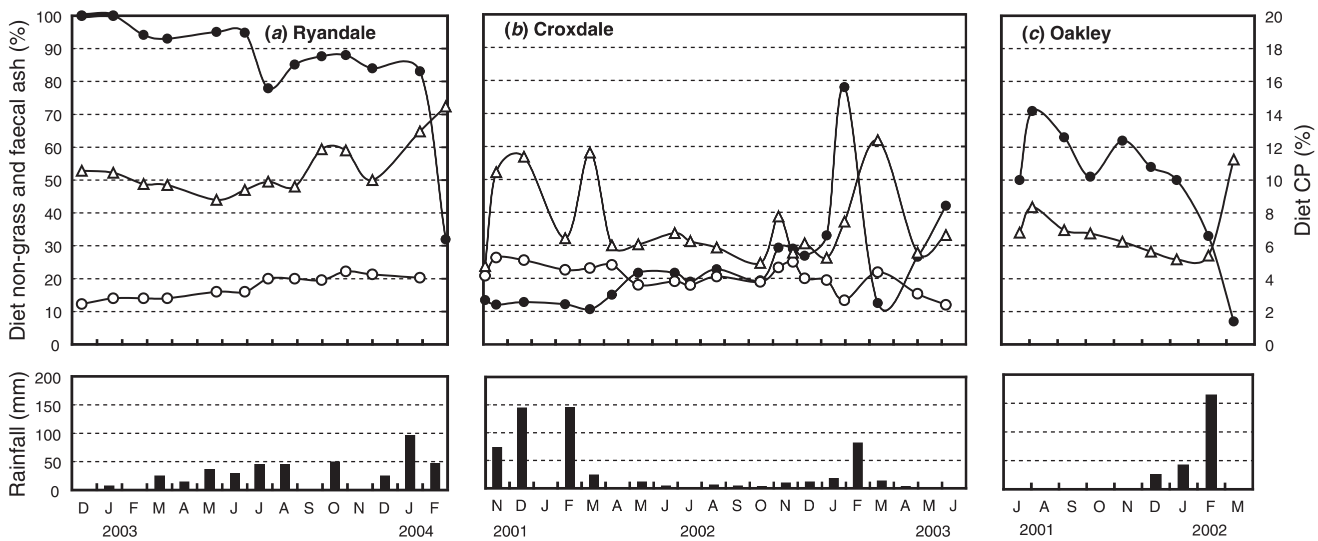

Fig. 4. Faecal NIRS predictions of diet non-grass proportions (●), crude protein concentration (△), and faecal ash (○), together with monthly rainfall at (*a*) Ryandale near Cunnamulla, (*b*) Croxdale near Charleville, and (*c*) Oakley Station near Torrens Creek.

probably principally browse. Forbs may have contributed to the diet after the rain in January–February 2002, though diet CP did not increase until March when the diet was principally grass.

Relationship between diet non-grass proportions and protein in the diet

The linear relationships ($P < 0.05$) between diet CP and DNG for dry season samplings at Newcastle Waters and Carlton Hill Station (Fig. 5) indicated that the protein content of the non-grass was higher than that of the grass in each of these circumstances. The intercepts of the regressions indicated that the protein content of the grass selected ranged from 3.1–5.3%, and the slopes indicated that the protein content of the non-grass selected ranged from 12.0–15.1% for the Newcastle Waters and Carlton Hill sites. Thus, for every 10% increase in DNG, the CP of the entire diet increased by 0.8–1.1%. The regressions for the two sampling dates at Newcastle Waters suggested that CP of the grass selected decreased from 5.3 to 3.6%, and CP of the non-grass selected decreased from 15.1 to 12.5%, during the interval between samplings. Similarly, at Woolthorpe (Fig. 6) the CP contents of the selected grasses and non-grasses were 4.7 and 12.9% in June, and 4.5 and 15.5% in July, respectively. Also the DM digestibilities of the selected grasses and non-grasses at Woolthorpe were 53 and 73% in June, and 50 and 74% in July.

Discussion

Use of F.NIRS technology to measure the proportion of non-grass in the diet selected by grazing cattle (or sheep), as in the present study, involved both advantages and limitations. The F.NIRS technique allowed frequent, low-cost measurements of many dietary attributes in herds grazing many sites and a range of pasture systems over long periods, and DNG was but one such attribute. This would have been difficult to achieve with any other existing technology. Furthermore, since the measurement was based on faeces obtained from many animals grazing paddocks without restriction, many of the errors associated with use of

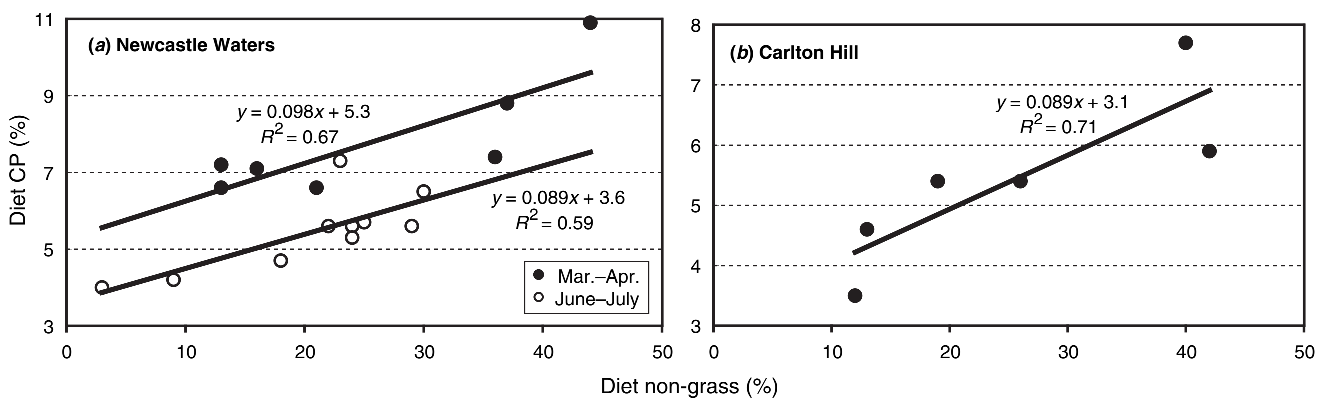

Fig. 5. The relationship between F.NIRS predictions of diet crude protein (CP) and diet non-grass proportions. Predictions were made on faeces from 6–10 mobs of cattle sampled at different watering points or different paddocks at (*a*) Newcastle Waters, NT, in March–April and June–July of 2004, and (*b*) Carlton Hill Station, WA in August 2001.

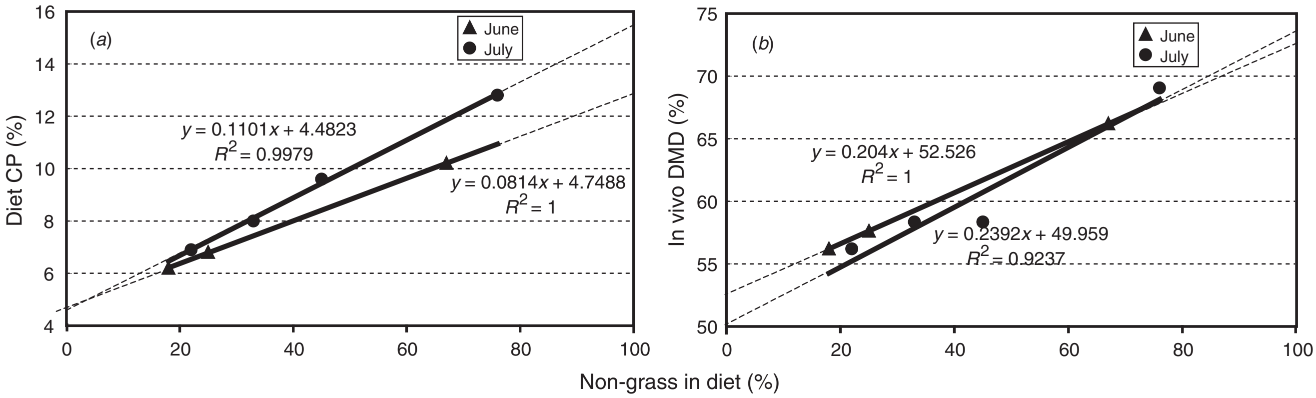

Fig. 6. The relationship between (*a*) diet crude protein (CP) and diet non-grass and (*b*) DM digestibility and diet non-grass. Predictions represented sheep from three paddocks in June and four paddocks in July of 2003.

oesophageal fistulated animals to measure diet selection were avoided. With oesophageal-fistulated animals there are always concerns about whether the extrusa sampled is representative of the daily intake, whether the area grazed during sampling is representative of the paddock, and whether a few surgically modified animals introduced briefly to the specific grazing situation will accurately represent the diet selected by long-term resident animals (Coates *et al*. 1987; Jones and Lascano 1992; Clements *et al*. 1996). Microhistological analysis of plant cuticle in faeces to identify the plant species avoids many of the latter difficulties, but quantitative determination of the proportions of the various plant species selected in the diet often involves large errors and the technique is very laborious (Holechek *et al*. 1982). Estimates of the diet selected from observing grazing animals, or by measuring the disappearance of vegetation components, also involve major limitations. Alkane and other plant wax compounds have been used as markers to measure diet selection in temperate pastures (Dove and Mayes 1991, 2005; Ali *et al*. 2005), but the presently available methods cannot measure the botanical composition of the diet where animals may be selecting a substantial number of plant species. There are additional difficulties with the application of this marker technology to cattle grazing in the tropics, since the alkane concentrations are low and variable in many tropical pasture species (Laredo *et al*. 1991; Reich *et al*. 2000). An obvious limitation of using F.NIRS to measure the $\delta^{13}C$ of the diet is that the diet can be divided into only two botanical classes, and the non-grass class may include browse species, leguminous forbs, and non-leguminous forbs. Estimation of the plant species which comprise the grass or non-grass classes must depend on other knowledge such as the measurement or observation of the plant species available and apparently being selected by the grazing animals. Furthermore some of the grass species available in the sub-tropics are C_3 (Hattersley 1983) and some forb species in Mitchell grass dominated pastures are C_4 (Cobon and Carter 1994). However, as discussed by Coates (2004), the calibration equation he developed is probably measuring plant tissue characteristics rather than actual $^{12}C/^{13}C$ ratios, and the predictions of DNG when these C_3 grasses and C_4 forbs contribute to the diet approximate the true values unless they are present in very high proportions. Despite these limitations F.NIRS technology is extremely valuable in allowing frequent measurement of the diet, including grass and non-grass proportions, in circumstances where this would otherwise not be possible.

In the absence of ongoing, detailed information on the botanical composition of the vegetation on offer at the sites we sampled, we could not assign selection preferences to different classes of plants. However, measured DNG at the browse sites at Ryandale, Croxdale and Oakley Station appeared to be consistent with selection preferences of cattle and sheep grazing the arid rangelands of southern Australia as described by Wilson and Harrington (1984), who grouped plant species into four main categories according to the order in which they are selected by livestock during the usual seasonal progression from active pasture growth through to maturity and senescence. First preference during the period of active pasture growth was usually for some perennials and a wide array of ephemeral plants (annual grasses and forbs) when these were available (category 1). Second preference (category 2) was for the more palatable perennials when the ephemerals had either dried off or had been grazed down. Grazing then turned to lower palatability plants (category 3) that were eaten in increasing amounts when the availability of palatable plants was reduced and included browse species such as mulga and saltbush and a range of perennial grasses such as Mitchell grasses. The fourth category included species which are rarely or never eaten, usually because of the presence of antinutritional factors, protective physical features or extreme fibrousness. Similar results for sheep in semi-arid mulga woodland were reported by Freudenberger *et al*. (1999) who also emphasised preference for green grass leaf when it was available, and also for cattle as well as sheep for other Australian rangeland regions (Squires 1980; Squires and Siebert 1983; McMeniman *et al*. 1986; Squires and Low 1987).

Faecal profiles for DNG at the browse sites appeared to be consistent with these published selection sequences. At Ryandale the only feed available when sampling commenced was mulga and it constituted the entire diet. Rain was received through the autumn and winter months (Fig. 4*a*) but DNG remained very high throughout this period. As we explained in the results section we suggest there was a change in diet selection from mulga (category 3) to forbs (category 1) that germinated and grew in response to autumn-winter rain, and that rainfall was insufficient at that time to stimulate appreciable grass growth until substantial rain fell in January, after which grass (category 1 or 2) then became the dominant dietary component. At Croxdale DNG was around 10% during the pasture growing season November–March (Fig. 4*b*) and we concluded that green grass was either preferred to the available forbs or that low availability of palatable forbs prohibited high intakes. However, as the pasture dried off and grass protein concentrations declined there was an increase in non-grass consumption to alleviate the protein deficiency. We proposed that this increase in DNG (April–August) was not the result of cattle eating mulga (category 3) and that high intakes of mulga (reaching nearly 80% in January) only occurred late in the dry period when other more palatable sources of non-grass forage were depleted. Following substantial rain in February grass became the dominant dietary component. Similarly, browse was a major dietary component during the long dry season at Oakley Station but, with wet season rains, cattle reverted to a diet of grass.

At the Mitchell grass dominated sites, with the exception of Morungle, the non-grass component was necessarily forbs due to the absence of browse. Lack of pasture composition data (except for early dry season and late dry season measurements at Toorak) again made it impossible for us to assign grazing preferences to the grass and non-grass fractions but high DNG was consistent with previous measurements in oesophageal-fistulated sheep grazing Mitchell grass dominated pastures (Lorimer 1978; McMeniman *et al*. 1986; Orr *et al*. 1988). We conclude that many forb species present in Mitchell grass-dominated pastures are palatable and readily grazed by cattle during the wet season when green grass leaf is also available. Moreover, we propose that, where both green grass and young forbs are readily available, cattle prefer a mixed diet rather than a diet heavily biased towards either category. During the dry season the protein concentration in dry grass falls to low levels and cattle exhibit a strong preference for forbs. This was particularly well demonstrated at Toorak in 2002 when forbs accounted for less than 2% of the pasture on offer in May but cattle selected a diet averaging ~15% non-grass throughout the long dry season. Forbs were more prevalent at Toorak in 2003 and 2004 and cattle again selected strongly for forbs during the dry season. Although sheep have a greater ability than cattle to select some vegetation components (Wilson 1976; Graetz and Wilson 1980; Squires 1980), these results from Toorak indicate that cattle also have the ability to select the forb component in Mitchell grass dominated pastures.

Non-grass levels in the diet of cattle grazing grasslands of the black speargrass and *Aristida–Bothriochloa* regions at moderate stocking rate were much lower than those of the Mitchell grass pastures and those that were measured at times in the browse communities. A range of factors contribute to diet composition but of primary importance are the species on offer and their availability. Since adapted perennial grasses dominate these grasslands when grazed at moderate rates, forbs generally only account for a small proportion of the pasture on offer. Moreover, the native woody vegetation is usually unpalatable and only eaten when alternative forage is depleted. Therefore, on the grounds of availability, forbs would be unlikely to make a major contribution to intake in the long term. Obviously relative palatability would also be a major determinant of diet grass/non-grass composition, when both components are available to livestock. Ash *et al*. (1995) reported a seasonal pattern similar to that which we measured at Swans Lagoon for northern speargrass pastures near Charters Towers, Queensland, and for monsoonal tallgrass pastures near Katherine. Low proportions of non-grass were selected during the wet season, followed by higher proportions in the late wet season which then declined through the dry season. This pattern was consistent with other experiments in monsoonal tallgrass pastures (Andrew 1986; Hendricksen *et al*. 1999) where it was concluded that cattle did not actively select forbs, or selected against the forbs, in favour of grasses especially when the grasses were actively growing. Several studies have shown that in pastures containing various species of introduced legumes, cattle primarily selected grasses during their interval of active growth and substantial amounts of legume were not selected until the late wet season or the dry season (Stobbs 1977; Gardener 1980; Coates 1996, 1999; Clements *et al*. 1996). The results from Swans Lagoon are therefore consistent with earlier work, in indicating that early in the wet season cattle obtain a large proportion of their diet from new grass growth and that the contribution of the forbs, when available, tends to increase in the late wet season and early in the dry season. The results from Swans Lagoon also indicated that browse can make an appreciable contribution to the diet of cattle in eucalypt woodlands at the end of long dry seasons.

Several studies (Squires 1980; Holm and Eliot 1980; Hall 1981; Ash *et al*. 1995) have reported that both the forb and browse on offer in seasonally dry rangeland environments is often higher in nitrogen, phosphorus and metabolisable energy (ME) than grasses, particularly when grasses are senesced. The results from Newcastle Waters, Carlton Hill and Woolthorpe (Figs 5, 6) highlighted the marked difference in CP concentration between the grass and non-grass dietary fractions and the impact of DNG on diet CP. The Woolthorpe results also demonstrated a similar effect with respect to digestibility and therefore ME intake. Thus, selection of the non-grass components of pasture by grazing cattle may appreciably alleviate the deficiencies of essential nutrients, particularly nitrogen and ME during the dry season, though the presence of condensed tannins in many browse species can reduce availability to the animal of both protein and energy.

In contrast to the Swans Lagoon site, DNG appeared to be much less related to season or rainfall at Brian Pastures, Glentulloch and Forest Home. Although it was not possible to relate changes in DNG to amounts or proportions of forbs in the pasture, there appeared to be little or no evidence for strong selection by cattle for forbs over immature regrowth of perennial grasses.

The effect of grazing pressure on DNG in the Glentulloch experiment was substantial in one replicate but not significant overall. Nevertheless, the results presented in Fig. 2 demonstrate the benefits of F.NIRS profiles of DNG and diet quality as an aid to interpreting paddock and treatment differences (or lack thereof) in both pasture and animal production traits. Although the difference was not significant at Glentulloch, Ash *et al*. (1995) reported higher DNG and higher diet quality as a consequence of prolonged high grazing pressure at sites near Charters Towers in the northern speargrass region and near

Katherine in the monsoonal tallgrass region. The underlying cause is probably related to changes in the botanical composition of native pastures where prolonged high grazing pressure leads to a reduction in the perennial grass component, especially the palatable perennials, and an increase in the amount and proportion of forbs. The effect has been recorded for speargrass pastures (Ash and McIvor 1995), monsoonal tallgrass pastures (McIvor *et al*. 1995), Mitchell grass dominated pastures (Orr 1980), and in rangelands of the Americas (Smith *et al*. 1994). The increases in DNG and diet CP during years 3 and 4 at Swans Lagoon (Fig. 1*a*) were also consistent with these observations and were probably the result of higher than normal grazing pressure due to a sequence of years with well below average rainfall.

The faecal profiles we presented in this paper covered a wide range of grazed pasture systems with respect to geographical location, climatic factors, soils and vegetation. They demonstrated the results that can be achieved using F.NIRS technology in association with frequent, regular sampling over prolonged periods. These profiles from 12 different sites were merely a selection from many such profiles that we developed during the course of our F.NIRS research over the past decade. They illustrate the power of this technology to provide a wealth of information in a low cost and timely manner where sampling is simple and the requirement for skilled technical support is minimal. Similar information on dietary grass/non-grass proportions for cattle grazing vegetation where the grass/non-grass ratio equates with the C_4/C_3 ratio can be obtained by mass spectrometry analysis at similar cost. However, F.NIRS has the capacity to measure a range of other dietary attributes at no additional analytical cost, so that cost effectiveness is greatly enhanced. For example, at the present stage of development, reliable predictions of diet CP, digestibility, faecal N, diet non-grass and faecal ash are made on a routine basis for faecal samples analysed using NIRS. As the technology continues to develop the range of analytes will increase. We have demonstrated how the concurrent determination of several attributes helps in the interpretation of results such as in differentiating between browse and forbs in the diet based on faecal ash and quantifying the importance of diet non-grass with respect to the protein status of the diet.

Faecal NIRS analysis is now accepted as a legitimate research tool and is being employed in many grazing studies to provide an understanding of diet selection, diet quality and composition, differences between treatments mediated via factors such as pasture species, grazing system, or management interventions like fire, and issues related to biodiversity and sustainability. Reliable estimates of DNG are important in this context. Also, F.NIRS prediction of DNG has proven to be a beneficial educational tool not only for beef producers but for scientists, technicians, extension personnel and others involved in the extensive grazing industry. In the past decade over 35 000 faecal samples have been analysed by CSIRO in Townsville using NIRS and more than half have been submitted by commercial beef producers. The prediction of diet non-grass has revealed to producers the importance of non-grass pasture components as a forage resource, not only in relation to the contribution non-grass makes to total intake but also to diet quality and especially the protein status of the diet. Although non-grass has long been recognised as a major forage resource in regions such as the arid shrublands, Mitchell grass areas and Channel Country, the importance of non-grass in the savannahs of northern Australia where perennial grasses dominate the pasture has often been either not recognised or underrated. Even in the Mitchell grass regions the importance of forbs in providing nutrients and energy to grazing livestock has probably not been fully appreciated. Faecal NIRS provides a practical and inexpensive means by which this type of information can now be made available to commercial operators and the information becomes all the more relevant when it applies to the operator's own property.

Predictions of diet non-grass by F.NIRS can also be considered a decision support tool. Any technology that provides managers with a greater understanding of how their enterprises function is likely to help managers make better decisions. As an example, consider dry season N supplementation in the Mitchell grass areas where livestock obtain energy and protein from grass and forbs. Once grasses dry off in the dry season, protein levels will be low and, if forbs are not available to grazing livestock, they are likely to suffer a deficiency of rumen degradable protein. However, if forbs are available they can provide sufficient protein, thus avoiding the need for N supplementation. The results for diet non-grass from Toorak, where no browse was available, showed that cattle, as well as sheep, have an extraordinary ability to seek out forbs even when present in very low amounts and where they may not be apparent to the casual observer. Faecal NIRS predictions of diet non-grass in such situations can be a valuable tool to assist producers make economically important decisions regarding the need to supplement or not throughout the course of the dry season.

Future opportunities

As stated previously, a major limitation of F.NIRS estimates of diet composition based on predictions of faecal $\delta^{13}C$ is that the diet can only be divided into grass and non-grass. Although this two-class division is useful, an ability to distinguish between species or groups of species within either class would be highly desirable. Other work has shown that F.NIRS calibration equations can be developed to measure botanical composition of the diet, at least in defined circumstances (Walker *et al*. 1998, 2002; Landau *et al*. 2004). Evidence from our own research to date indicates that it is not likely that F.NIRS has the capacity to distinguish between multiple species such as between many different grass species in a diet. However, early work to develop a calibration equation for predicting the dietary proportions of (i) mulga and (ii) *Stylosanthes* legume has been encouraging. Spectral analysis using advanced chemometrics may also enhance the discriminatory power of NIRS in general and F.NIRS in particular. Similarly, combining F.NIRS technology with other new technologies may lead to improved outcomes. For example, DNA analysis shows promise for the identification of plant species in faeces and the two technologies (F.NIRS and DNA) combined may produce better outcomes than either technology separately.

The results presented in this paper relate to northern Australia where most grasses are C_4 and most non-grasses are C_3. Our calibration equation and the calculation of diet non-grass cannot be applied as it currently exists to pastures in southern Australia where there are many native and introduced C_3 grasses and vast areas such as the Chenopod shrublands where a C_4 non-grass species (saltbush) forms a major component of the forage resource. Nevertheless, we believe that with appropriate research, F.NIRS has the potential to provide useful information on the botanical composition of diets in southern Australia.

Conclusions

The contribution of non-grass to the diets of cattle grazing the rangelands of northern Australia can be easily and reliably estimated using F.NIRS. The non-grass fraction can make a substantial contribution to the diet in terms of proportional DM and protein status. Since the protein level of grass during the dry season is generally well below maintenance requirements for cattle, the edible non-grass components of the vegetation form an important part of the fodder resource, even where grasses dominate.

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